FORM PTO-1390 (REV 5-93)

U S DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER
127FR/49857

U S. APPLICATION NO (if known, see 37 CFR 1 5)
09/868251

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/EP99/09966	15 December 1999	15 December 1998

TITLE OF INVENTION
Controlled Acoustic Waveguide for Sound Absorption

APPLICANT(S) FOR DO/EO/US
Jan KRUEGER and Philip LEISTNER

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. [X] This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.

2. [ ] This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371

3. [ ] This express request to begin national examination procedures (35 U.S.C. 371(f) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).

4. [X] A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.

5. [X] A copy of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. [X] is transmitted herewith (required only if not transmitted by the International Bureau).
   b. [ ] has been transmitted by the International Bureau
   c. [ ] is not required, as the application was filed in the United States Receiving Office (RO/US)

6. [X] A translation of the International Application into English (35 U.S.C. 371(c)(2)).

7. [ ] Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. [ ] are transmitted herewith (required only if not transmitted by the International Bureau).
   b. [ ] have been transmitted by the International Bureau.
   c. [ ] have not been made; however, the time limit for making such amendments has NOT expired.
   d. [ ] have not been made and will not be made.

8. [ ] A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).

9. [X] An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)). (unexecuted)

10. [X] A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Item 11. to 16. below concern other document(s) or information included:

11. [X] An Information Disclosure Statement under 37 CFR 1.97 and 1.98.

12. [ ] An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.

13. [X] A FIRST preliminary amendment.
    [ ] A SECOND or SUBSEQUENT preliminary amendment.

14. [X] A substitute specification.

15. [ ] A change of power of attorney and/or address letter.

16. [X] Other items or information:

10 Sheets of Drawings showing Figs. 1-10
1st Page of Published International Application

23911
PATENT TRADEMARK OFFICE

JC18 Rec'd PCT/PTO 15 JUN 2001

U.S. APPLICATION NO. (if known, see 37 CFR 1.5) 09/868251	INTERNATIONAL APPLICATION NO PCT/EP99/09966	ATTORNEY'S DOCKET NUMBER 127FR/49857

17. [X] The following fees are submitted:

				CALCULATIONS	PTO USE ONLY
Basic National Fee (37 CFR 1.492(a)(1)-(5)):					
Search Report has been prepared by the EPO or JPO $860.00				$860.00	
International preliminary examination fee paid to USPTO (37 CFR 1.482) $690.00					
No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2) $710.00				$0.00	
Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37CFR 1.445(a)(2) paid to USPTO $1000.00					
International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) $100.00					
ENTER APPROPRIATE BASIC FEE AMOUNT =				$860.00	
Surcharge of $130.00 for furnishing the oath or declaration later than [ ] 20 [X] 30 months from the earliest claimed priority date (37 CFR 1.492(e)).				$130.00	
Claims	Number Filed	Number Extra	Rate		
Total Claims	14-20=	0	X $18.00	$0.00	
Independent Claims	2-3=	0	X $80.00	$0.00	
Multiple dependent claims(s) (if applicable)			+ $270.00	$	
TOTAL OF ABOVE CALCULATIONS =				$990.00	
Reduction by 1/2 for filing by small entity, if applicable. Verified Small Entity statement must also be filed. (Note 37 CFR 1.9, 1.27, 1.28).				$	
SUBTOTAL =				$990.00	
Processing fee of $130.00 for furnishing the English translation later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +				$--	
TOTAL NATIONAL FEE =				$990.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28,3.31). $40.00 per property +				$--	
TOTAL FEE ENCLOSED =				$990.00	
				Amount to be: refunded	$
				charged	$

a. [X] One check in the amount of $ 990.00 for the filing fee and surcharge is enclosed
b. [ ] Please charge my Deposit Account No. ______ in the amount of $______ to cover the above fees. A duplicate copy of this sheet is enclosed.
c. [X] The Commissioner is hereby authorized to charge any additional fees, which may be required, or credit any overpayment to Deposit Account No. 05-1323 . (Attorney Dkt. 127FR/49857 A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:
Crowell & Moring, L.L.P.
1200 G Street, N.W., Suite 700
Washington, D.C. 20005
Tel. No. (202) 628-8800
Fax No. (202) 628-8844

SIGNATURE
James F. McKeown
NAME
25, 406
REGISTRATION NUMBER
June 15, 2001
DATE

Attorney Docket: 127FR/49857
PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: JAN KRUEGER ET AL.

Serial No.: 09/868,251

Filed: JUNE 15, 2001

Title: CONTROLLED ACOUSTIC WAVEGUIDE FOR SOUND ABSORPTION

PRELIMINARY AMENDMENT

Box Non-Fee Amendment
Commissioner for Patents
Washington, D.C. 20231

Sir:

Please enter the following amendments to the specification prior to the examination of the application.

IN THE SPECIFICATION:

Please amend the specification as follows:

(A copy of the marked up version of amended paragraphs of the specification is attached as an appendix to this amendment.)

Please replace paragraph [0020] on page 6 with the following:

[0020] Fig. 5 is a graph of insertion loss measured on the controlled waveguide according to Fig. 4, with and without amplification;

Please replace paragraph [0021] on page 7 with the following:

[0021] Fig. 6 is a graph of insertion loss measured on the controlled waveguide according to Fig. 4, with amplification at an air temperature of 20 _C and 150 _C in the duct;

IN THE DRAWINGS:

A Request for Permission to Change the Drawings is submitted herewith.

REMARKS

Entry of the amendments to the specification before examination of the application is respectfully requested.

If there are any questions regarding this Preliminary Amendment or this application in general, a telephone call to the undersigned would be appreciated since this should expedite the prosecution of the application for all concerned.

It is respectfully requested that, if necessary to effect a timely response, this paper be considered as a Petition for an Extension of Time sufficient to effect a timely response and shortages in other fees, be charged, or any overpayment in

fees be credited, to the Account of Crowell & Moring LLP, Deposit Account No. 05-1323 (Docket #127FR/49857).

September 20, 2001

Respectfully submitted,

James F. McKeown
Registration No. 25,406

CROWELL & MORING, LLP
P.O. Box 14300
Washington, DC 20044-4300
Telephone No.: (202) 624-2500
Facsimile No.: (202) 628-5116

JFM/ajf

<u>Appendix to Amendment</u>

(Marked up version of amended specification)

In the specification, paragraph [0020] on page 6 is amended as follows:

[0020] Fig. 5 is a graph of insertion [attenuation] <u>loss</u> measured on the controlled waveguide according to Fig. 4, with and without amplification;

In the specification, paragraph [0021] on page 7 is amended as follows:

[0021] Fig. 6 is a graph of insertion [attenuation] <u>loss</u> measured on the controlled waveguide according to Fig. 4, with amplification at an air temperature of 20 _C and 150 _C in the duct;

09/868251
JC18 Rec'd PCT/PTO 15 JUN 2001

Attorney Docket: 127FR/49857
PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: JAN KRUEGER ET AL.

Serial No.: NOT YET ASSIGNED PCT NO.: PCT/EP99/09966

Filed: June 15, 2001

Title: CONTROLLED ACOUSTIC WAVEGUIDE FOR SOUND ABSORPTION

PRELIMINARY AMENDMENT

Box PCT
Commissioner for Patents
Washington, D.C. 20231

Sir:

Please enter the following amendments to the specification, claims and abstract prior to the examination of the application.

IN THE SPECIFICATION:

A substitute specification and a marked-up copy thereof is attached herewith.

IN THE CLAIMS:

Please cancel claims 1-13 and add new claims 14-27 as follows:

14. (New) Controlled acoustic waveguide for use with an elongate hollow chamber (1), connected to at least one sound-transmitting duct (4) via an opening (2) on its first end surface (3) thereof, comprising a microphone (10) for detecting membrane vibrations so as to allow tunability of

longitudinal resonances of the hollow chamber (1) to a sound spectrum to be attenuated, the microphone (10) being located directly in front of a membrane (8) of at least one loudspeaker (9) on a second end surface (6) the hollow chamber (1), and an amplifier (11) for inverting a microphone signal, with feedback of the inverted microphone signal to said loudspeaker (9) being in an amplified form in dependence on a sensor signal characteristic of sound in the sound-transmitting duct (4).

15. (New) Controlled waveguide according to claim 14, wherein the opening (2) is provided with a sound-transmitting protective cover (5) made of one of a perforated sheet, a non-woven material and sheet materials.

16. (New) Controlled waveguide according to claim 14, wherein the hollow chamber (1) projects one of orthogonally and obliquely from the duct (4) or conforms to a straight or bent wall of the duct (4).

17. (New) Controlled waveguide according to claim 16, wherein a thermal insulating layer (13) is provided between a wall of the duct (4) and a wall of the hollow chamber when the hollow chamber (1) conforms to the wall of the duct (4).

18. (New) Controlled waveguide according to claim 14, wherein at least one wall of the hollow chamber (1) is provided with cooling elements (11) at least over part of the surface of the at least one wall.

19. (New) Controlled waveguide according to claim 14, wherein the hollow chamber (1) has a forced cooling apparatus (15) a thermal exchanger type or a Peltier element type therein.

20. (New) Controlled waveguide according to claim 14, wherein transverse partitioning is arranged to subdivide the hollow chamber (1) into tubes of different lengths.

21. (New) Controlled waveguide according to claim 14, wherein walls of said hollow chamber (1) are provided with a sound absorptive cladding (17) over at least a portion of the surface or their entire surface thereof.

22. (New) Controlled waveguide according to claim 14, wherein the sensor signal is comprised of temperature sensors, rotational speed sensors and measuring elements for the gas flow of burners and exhaust gas systems characteristic of the sound spectrum occurring in the duct (4).

23. (New) Controlled waveguide according to claim 14, wherein a plurality of the at least one duct (4) have side walls with a rectangular cross-section and a plurality of controlled waveguides are thereon.

24. (New) Controlled waveguide according to the claim 14, wherein the hollow chamber (1) configured as a circular and extends along a periphery of a duct (4).

25. (New) Controlled waveguide according to the claim 14, wherein a central slide is positioned inside the duct (4) configured rectangular or cylindrically so as to present an aerodynamically configuration or cylindrical duct (4).

26. (New) Controlled waveguide according to claim 14, wherein an acoustically effective membrane or plate communicates with said duct (4) in lieu of the sound-transmitting opening.

27. (New) Method for absorbing sound using a controlled acoustic waveguide, comprising:

connecting an elongate hollow chamber to a sound-transmitting duct via an opening on a first end surface of the hollow chamber,

locating a microphone directly in front of a loudspeaker on a speaker on a second end surface of the hollow chamber,

detecting membrane vibrations of the loudspeaker via the microphone, inverting a microphone signal representative of the detected membrane vibrator, and amplifying and feeding both the inverted microphone signal to the loudspeaker in dependence on a signal characteristic of sound in the sound-transmitting duct. --

IN THE ABSTRACT:

Please substitute the new Abstract of the Disclosure submitted herewith on a separate page for the original Abstract presently in the application.

REMARKS

Entry of the amendments to the specification, claims and abstract before examination of the application is respectfully requested. These claims have been amended to remove multiple

dependencies. These claims patentably define over the art of record.

If there are any questions regarding this amendment or the application in general, a telephone call to the undersigned would be appreciated since this should expedite the prosecution of the application for all concerned.

Serial No. Not Yet Assigned

If necessary to effect a timely response, this paper should be considered as a petition for an Extension of Time sufficient to effect a timely response, and please charge any deficiency in fees or credit any overpayments to Deposit Account No. 05-1323 (Docket #127FR/49857).

June 15, 2001

Respectfully submitted,

McKeown

James F. McKeown
Registration No. 25,406

JFM/rrt

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-- **ABSTRACT OF THE DISCLOSURE**

A controlled acoustic waveguide of the type having an elongate hollow chamber which communicates with a sound-transmitting duct via an opening in its first end surface. The longitudinal resonances of the hollow chamber may be tuned to a sound spectrum to be attenuated. This is accomplished by detecting the membrane vibrations with a microphone located directly in front of the membrane of at least one loudspeaker on the second end surface of the hollow chamber, by inverting the microphone signal with an amplifier and by feedback of the inverted microphone signal to the loudspeaker in an amplified form in dependence on a sensor signal, which is characteristic of the sound in said duct. --

09/868251

Attorney Docket: 127FR/49857
PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: JAN KRUEGER ET AL.

Serial No.: 09/868,251

Filed: JUNE 15, 2001

Title: CONTROLLED ACOUSTIC WAVEGUIDE FOR SOUND ABSORPTION

REQUEST FOR PERMISSION TO CHANGE THE DRAWINGS

Commissioner for Patents
Washington, D.C. 20231

Sir:

Applicant hereby respectfully requests permission to change the drawing figures, Figures 5 and 6, as indicated in red shown on the attached sheets. These drawing changes do not add new matter to the application.

Respectfully submitted,

September 20, 2001

James F. McKeown
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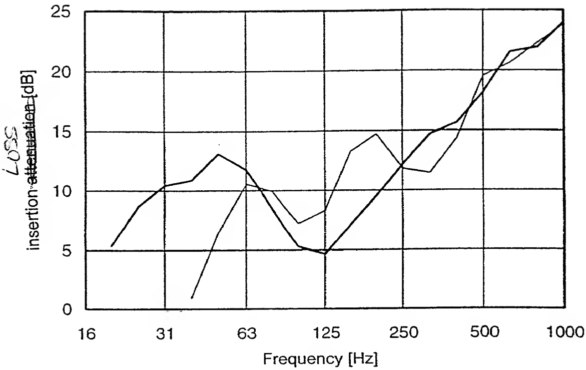
JFM/ajf



controlled waveguide according to Fig. 4 with amplifier (11) turned on at 20 °C in the duct (4)

controlled waveguide according to Fig. 4 with amplifier (11) turned on at 150 °C in the duct (4)

Fig. 5

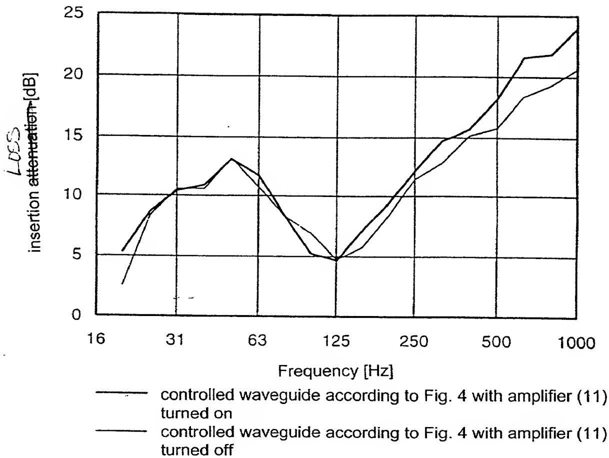

25
20
15
10
5
0
LOSS
insertion ~~attenuation~~ [dB]
16
31
63
125
250
500
1000
Frequency [Hz]
controlled waveguide according to Fig. 4 with amplifier (11) turned on
controlled waveguide according to Fig. 4 with amplifier (11) turned off

Fig. 6

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Attorney Docket: 127FR/49857
PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: JAN KRUEGER ET AL.

Serial No.: NOT YET ASSIGNED PCT NO.: PCT/EP99/09966

Filed: June 15, 2001

Title: CONTROLLED ACOUSTIC WAVEGUIDE FOR SOUND ABSORPTION

SUBMISSION OF SUBSTITUTE SPECIFICATION

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

Attached is a Substitute Specification and a marked-up copy of the original specification. I certify that said substitute specification contains no new matter and includes the changes indicated in the marked-up copy of the original specification.

Respectfully submitted,

June 15, 2001

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10/PRTS

09/868251
JC18 Rec'd PCT/PTO 15 JUN 2001

PCT/EP99/09966
Clean Specification
Attorney Docket No. 127FR/49857

Controlled Acoustic Waveguide for Sound Absorption

Background of the Invention

[0001] This application claims the priority of PCT International No. PCT/EP99/09966 filed December 15, 1999 and German Priority Document 198 61 018.1 filed December 15, 1998, the disclosures of which are expressly incorporated by reference herein.

[0002] The present invention relates to a controlled acoustic waveguide for sound absorption in the manner of an elongate hollow chamber which communicates with a sound--transmitting duct via an opening on its first end surface. The longitudinal resonances may be tuned to a sound spectrum to be attenuated, by detecting the membrane vibrations with a microphone located directly in front of the membrane of at least one loudspeaker on the second end surface of the hollow chamber and by inverting the microphone signal with an amplifier and by feedback of the inverted microphone signal to the loudspeaker in an amplified form in dependence on a signal from a sensor, which is characteristic of the sound in the duct.

[0003] Sound absorbers are known for attenuating low-frequency noise in ducts, wherein the longitudinal resonances of elongate hollow chambers, so-called acoustic waveguides, are utilized, e.g. in accordance with the DE 19612572 or Lamancusa, J.S.: "An actively tuned passive muffler system for engine silencing". Proceedings Noise-Con 87, 1987, pp. 313 - 318. These waveguides are coupled to the sound-transmitting duct via

an opening in the end surface thereof and either project orthogonally from the duct or conform thereto while extending in parallel therewith. For the first longitudinal resonance in particular, at which the length of the chamber corresponds to one quarter of the wavelength of the first resonance frequency, high attenuation levels are achieved over a narrow band. This limitation of the frequency range is, however, problematic when either a wide-band absorption is required or when the noise spectrum changes which was taken as a basis when the waveguide was dimensioned, The necessary adaptation of the chamber length is implemented, at least in stages, according to Lamancusa, by the provision of very long chambers with compartments from the very beginning, which may provision of very long chambers with compartments from the very beginning that be opened or closed whenever this is necessary. Another possibility of avoiding the inexpedient narrow-band restriction consists in the simultaneous application of different chamber lengths according to the German Document 196 12 572.

[0004] Another group of sound attenuators or absorbers for low frequencies comprises resonant cavities, i.e. both acoustic waveguides according to Okamoto, Y.; Boden, H.; Abom, M.: "Active noise control in ducts via side-branch resonators" in: Journ. of the Acoust. Soc. of America 96 (1994), No. 9, pp. 1533 - 1538, and equally Helmholtz resonators according to DE 4226885 or the US Patent No. 5233137, which are connected to a sound-transmitting duct or space via an opening and which have properties suitable for variation by electro-acoustical or active components, respectively. These systems share the joint approach that at least one microphone is present in the duct or space. The sound pressure signal so detected is initially filtered, amplified and subjected to further analysis

steps and then serves as control variable for at least one loudspeaker in the waveguide or cavity. As a result, the loudspeaker emits a signal which, again upon modification by the resonator, is superimposed with opposite phase onto the sound at the site of the microphone in the duct or cavity, so effecting attenuation of the sound. With these actively influenced resonators, it is possible, on the one hand, to generate and hence also attenuate high sound pressures at low frequencies while, on the other hand, at least the loudspeaker is protected from potential, e.g. thermal, loads in the duct. The disadvantages of these methods include the fixed dimensioning of the resonators independently of possible variations of the sound spectrum in the duct, which is initially taken as a basis, and the lack of protection of the microphone.

[0005] According to DE 4027511, a passive sub-system is used instead of the resonant cavities so far mentioned, which consists preferably of passive absorber layers and protecting cover layers. In this case, too, the function of the electro-acoustical components mounted on the rear side relates to the modification of the passive absorber, aiming at the generation of a theoretically optimum acoustic impedance on the front side of the absorber, which impedance promise the highest propagation attenuation possible in the connected sound-transmitting duct. This method requires that a signal-shaping circuit proposed in DE 4027511 firstly compensates the intrinsic characteristics of all the electro-acoustic components (microphone, loudspeaker, box, etc.) and secondly imprints on the system the desired terminating impedance. The characteristics of the components have been thoroughly studied and described. In accordance with the results the conversion

of this method into practice inevitably requires the implementation of complex transmission functions of the signal-shaping circuit, which cannot be realised in practical application except in approximation.

[0006] Reactive sound absorbers are operative without any additional passive layers or resonance systems according to WO 97/43754, wherein the membrane of a loudspeaker is a direct component of the wall in a sound-transmitting duct and wherein the membrane vibrations controlled or amplified with a feed-back circuit take a direct influence on the sound field in the duct. The adaptation to a sound spectrum to be attenuated, which is also necessary in this case, is based on the dimensioning of the resonance system consisting of the membrane mass and the pneumatic cushion in the form of the rear volume, which exists there-behind.

SUMMARY OF THE INVENTION

[0007] It is an object of the present invention to improve the efficiency of sound attenuation in ducts or the like and to reduce the manufacturing costs of the inventive device.

[0008] This problem has been solved by the device of the present invention in which the longitudinal resonances of said hollow chamber are tunable to a sound spectrum to be attenuated, by detecting the membrane vibrations by a microphone located directly in front of the membrane of at least one loudspeaker on the second end surface of said hollow chamber, and by inverting the microphone signal by an amplifier and by feedback of the inverted microphone signal to said loudspeaker in an amplified form in dependence on a signal from a sensor, which is characteristic of the sound in the duct.

[0009] The advantages of the present invention over existing sound absorber includes the following features:

[0010] In distinction from known acoustic waveguides, the controlled waveguide of the present invention achieves a high sound attenuation at low frequencies at a reduced structural volume (with the length of the hollow chambers reduced by up to roughly four times).

[0011] The frequency range with a high sound absorption of the inventive controlled waveguide is extended to roughly two octaves due to the adaptivity to variable acoustic spectrums.

[0012] The controlled waveguide of the present invention is characterized by a simple structure and particularly by a low-price analog amplification and control without expensive electronic filters or digital signal analysis,

[0013] Furthermore, all the electro-acoustic components in the hollow chamber of the controlled waveguide of the present invention are protected from influences produced by flow, dust and aggressive media in the duct over rather long periods.

[0014] This protection is also extended to high temperature, e.g. in exhaust gas systems, because the inventive controlled waveguide offers various possibilities of an efficient thermal decoupling from the duct.

Brief Description of the Drawings

[0015] Other objects, advantages and novel features of the present invention will become apparent from the

following detailed description of the invention when considered in conjunction with the accompanying drawings.

[0016] Fig. 1 is a schematic view of the controlled waveguide in accordance with the present invention;

[0017] Fig. 2 is a schematic view of an embodiment of the controlled waveguide with a thermal insulating layer between the hollow chamber and the duct, with cooling elements as part of the wall of the hollow chamber, with a forced cooling thermal exchanger, as well as with an absorbing inner wall cladding ;

[0018] Fig. 3 is a schematic view of another embodiment of the controlled waveguide of the present invention with a subdivision of the hollow chamber into several tubes of different lengths;

[0019] Fig. 4 is a schematic view of still another embodiment of the controlled waveguide with a conventional passive attenuator on the opposite duct wall (with dimensions indicated in mm);

[0020] Fig. 5 is a graph of insertion attenuation measured on the controlled waveguide according to Fig. 4, with and without amplification;

[0021] Fig. 6 is a graph of insertion attenuation measured on the controlled waveguide according to Fig. 4, with amplification at an air temperature of 20 °C and 150 °C in the duct;

[0022] Fig. 7 is a schematic view of a controlled waveguide with a hollow chamber projecting obliquely from the duct;

[0023] Fig. 8 is a schematic view of a controlled waveguide with a hollow chamber conforming to a bent duct;

[0024] Fig. 9 is a schematic view of a controlled waveguide with an aerodynamically expedient configuration and positioning in the manner of a central slide inside a large duct; and.

[0025] Fig. 10 is a schematic view of yet another embodiment of a controlled waveguide

DETAILED DESCRIPTION OF THE DRAWINGS

[0026] The starting point of the controlled waveguide according to Fig. 1 consists in an elongate hollow chamber (1) presenting distinct longitudinal resonances. The chamber (1) is acoustically connected via an opening (2) on the first end surface (3) to a sound-transmitting duct (4) or space. The length L of the hollow chamber (1) is dependent on the sound spectrum occurring in the duct (4), wherein the frequencies with the greatest sound amplitude vary within a defined range,

e. g. as a consequence of a varying gas temperature in the duct (4), as a function of the operation. In this case the length L corresponds to roughly one quarter of the wavelength of the upper limit frequency of this range.

[0027] The membrane (8) of at least one loudspeaker (9) is provided on the second end surface (6) of the hollow chamber (1), in front of another cavity (7), with the cavity (7) acting as air cushion and the membrane (8) as planar mass forming a resonance system. A microphone (10) is positioned directly in front of the membrane for detecting the membrane vibrations. The microphone signal is applied on the input of an inverting amplifier (11) with an adjustable gain, which produces an output signal, which serves to control the loudspeaker (9).

[0028] As a function of the level of amplification the membrane vibrations hence the acoustically effective length of the hollow chamber (1) undergo a variation, with the acoustic length being definitely (roughly four times) greater than the actual length L. The acoustically effective prolongation of the hollow chamber (1), which is achieved on account of the increased amplification, means a shift of its first longitudinal resonance towards lower frequencies, expediently up to the lower limit of the frequency range of the sound spectrum occurring in the duct (4). The setting of the gain is based on the control signal of at least one additional sensor (12) which supplies a parameter to the amplifier (11) that is characteristic of the frequencies having the highest sound amplitude in the duct.

[0029] Temperature sensors in the duct (4), rotational speed detectors on ventilators, generators or motors or engines, as

well as elements measuring the gas flow of burners and exhaust systems may be enumerated as examples of a sensor (12). The sensor (12) is expediently operative without particular protective measures such as those required, for instance, in microphones in an exhaust system. An exemplary and particularly simple configuration of the sensor (12) is a temperature-dependent resistor which detects the temperature in the duct (4) and constitutes, at the same time, an element of the feedback branch of an inverting amplifier (11) known per se and hence controls the overall gain achieved by this amplifier. Further expedient embodiments include the application of voltage- and current-controlled amplifiers (11) which broaden the range of contemplated sensors (12) available for selection.

[0030] A sound-transmitting cover (5) consisting of perforated sheet, non-woven material, sheet material or the like is provided in front of or behind the opening (2) leading to the duct (4) for protection from a possible soiling of the hollow chamber (1) and from entering hot exhaust gas from the duct (4). As a function of structural conditions in the environment of the duct (4), the hollow chamber (1) may be configured in a straight or curved shape, project obliquely or orthogonally from the duct, or conform against the duct (4) in the longitudinal direction. In this case, a thermal insulating layer (13) is disposed between the hollow chamber (1) and the duct (4), as may be seen in Fig. 2. Whenever the hollow chamber (1) must be expected to be heated, the cooling elements (11) illustrated in Fig. 2 as part of the wall of the hollow chamber improve the dissipation of heat in the same manner as a forced cooling of the kind of a thermal exchanger (15) or with so-called Peltier elements in the hollow chamber. A transverse subdivision (16) of the hollow chamber (1) into several tubes

of different lengths as well as an absorbing inner wall cladding (17) constitute another advantageous embodiment of the inventive controlled waveguide (Fig. 3) so as to achieve a broader-band attenuation.

[0031] Fig. 4 illustrates an embodiment of the inventive controlled waveguide in which the attenuation levels achieved in combination with a conventional passive attenuator (18) on the opposite duct wall, which are indicated in Fig. 5, represent the two boundary cases in the frequency range as a function of the set gain (11). The contrastive indication of the attenuation measured at 20 °C and 150 °C in the duct, which is presented in Fig. 6, emphasizes the low influence of temperature on the attenuation of the inventive controlled waveguide according to Fig. 4.

[0032] Figs. 7 through 10 show further embodiments of the controlled waveguide of the present invention. Similar reference numerals have been used to designate parts having functions similar to the described in conjunction with the embodiments of Figs. 1 through 4

[0033] The foregoing disclosure has been set forth merely to illustrate the invention and is not intended to be limiting. Since modifications of the disclosed embodiments incorporating the spirit and substance of the invention may occur to persons skilled in the art, the invention should be construed to include everything within the scope of the appended claims and equivalents thereof.

Patent Claims

1. Controlled acoustic waveguide of the type of an elongate hollow chamber (1), which is connected to a sound-transmifting duct (4) via an opening (2) on its first end surface (3), **characterised** in that the longitudinal resonances of said hollow chamber (1) are tunable to a sound spectrum to be attenuated, by detecting the membrane vibrations by means of a microphone (10) located directly in front of the membrane (8) of at least one loudspeaker (9) on the second end surface (6) of said hollow chamber (1), and by inverting the microphone signal by means of an amplifier (11) and by feedback of the inverted microphone signal to said loudspeaker (9) in an amplified form in dependence on a signal from a sensor (12), which is characteristic of the sound in said duct (4).

2. Controlled waveguide according to Claim 1, **characterised** in that said opening (23) is provided with a sound-transmifting protective cover (5) made of a perforated sheet, a non-woven material or sheet materials.

3. Controlled waveguide according to Claims 1 and 2, **characterised** in that said hollow chamber (1) projects orthogonally or obliquely from said duct (4) or conforms to the straight or bent wall of the duct.

4. Controlled waveguide according to the Claims 1 to 3, **characterised** in that a thermal insulating layer (13)

is provided between the duct wall and the wall of said hollow chamber when said hollow chamber (1) conforms to the wall of said duct (4).

5. Controlled waveguide according to the Claims 1 to 4, **characterised** in that the wall of said hollow chamber (1) are provided with cooling elements (11) either over part of their surface or their entire surface.

6. Controlled waveguide according to the Claims 1 to 5, **characterised** in that a forced cooling (15) means of the type of a thermal exchanger or Peltier elements is provided in said hollow chamber (1).

7. Controlled waveguide according to the Claims 1 to 6, **characterised** in that said hollow chamber (1) is subdivided into tubes of different lengths by means of a transverse partitioning.

8. Controlled waveguide according to the Claims 1 to 7, **characterised** in that the walls of said hollow chamber (1) are provided with a sound absorptive cladding (17) either over parts of their surface or their entire surface.

9. Controlled waveguide according to the Claims 1 to 7, **characterised** in that temperature sensors, rotational speed sensors as well as measuring elements for the gas flow of burners and exhaust gas systems are employed as sensor (12) for the sound spectrum occurring in said duct (4).

10. Controlled waveguide according to the Claims 1 to 9, **characterised** in that several controlled waveguides are used on several side walls of ducts (4) having a rectangular cross-section.

11. Controlled waveguide according to the Claims 1 to 9, **characterised** in that a c circular hollow chamber (1) is used which extends along the periphery about a cylindrical duct (4).

12. Controlled waveguide according to the Claims 1, 2 and 6 to 9, **characterised** in that the controlled waveguide presents an aerodynamically expedient design and is positioned in the manner of a central slide inside a large rectangular or cylindrical duct (4).

13. Controlled waveguide according to the Claims 1 and 3 to 9, **characterised** in that an acoustically effective membrane or plate instead of said sound-transmitting opening (2) constitutes the communication with said duct (4).

Abstract of the disclosure

The present invention relates to a controlled acoustic waveguide of the type of an elongate hollow chamber (1) which communicates with a sound-transmitting duct (4) via an opening (2) in its first end surface (3), wherein the longitudinal resonances of the hollow chamber (1) may be tuned to a sound spectrum to be attenuated, by detecting the membrane vibrations by means of a microphone (10) located directly in front of the membrane (8) of at least one loudspeaker (9) on the second end surface (6) of said hollow chamber (1), and by inverting the microphone signal by means of an amplifier (11) and by feedback of the inverted microphone signal to said loudspeaker (9) in an amplified form in dependence on a signal from a sensor (12), which is characteristic of the sound in said duct (4).

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Marked-up Specification
Attorney Docket No. 127FR/49857

Controlled Acoustic Waveguide for Sound Absorption

[Description]

Background of the Invention

This application claims the priority of PCT International No. PCT/EP99/09966 filed December 15, 1999 and German Priority Document 198 61 018.1 filed December 15, 1998, the disclosures of which are expressly incorporated by reference herein.

[1 . Subject matter of the invention]

The present invention relates to a controlled acoustic waveguide for sound absorption in the manner of an elongate hollow chamber[,] which communicates with a sound-transmitting duct via an opening on its first end surface. [and wherein the] The longitudinal resonances may be tuned to a sound spectrum to be attenuated, by detecting the membrane vibrations [by means of] with a microphone located directly in front of the membrane of at least one loudspeaker on the second end surface of the hollow chamber[,] and by inverting the microphone signal [by means of] with an amplifier and by feedback of the inverted microphone signal to the loudspeaker in an amplified form in dependence on a signal from a sensor, which is characteristic of the sound in the duct.

[2. Prior Art]

Sound absorbers are known for attenuating low-frequency noise in ducts, wherein the longitudinal resonances of elongate hollow chambers, so-called acoustic waveguides, are [utilised]

utilized, e.g. in accordance with the [German Patent] DE 19612572 or Lamancusa, J.S.: "An actively tuned passive muffler system for engine silencing". Proceedings Noise-Con 87, 1987, pp. 313 - 318. These waveguides are coupled to the sound-transmitting duct via an opening in the end surface thereof and either project orthogonally from the duct or conform thereto while extending in parallel therewith. For the first longitudinal resonance in particular, at which the length of the chamber corresponds to one quarter of the wavelength of the first resonance frequency, high attenuation levels are achieved over a narrow band. This limitation of the frequency range is, however, problematic when either a wide-band absorption is required or when the noise spectrum changes which was taken as a basis when the waveguide was dimensioned, The necessary adaptation of the chamber length is implemented, at least in stages, according to Lamancusa, by the provision of very long chambers with compartments from the very beginning, which may provision of very long chambers with compartments from the very beginning[, which may] that be opened or closed whenever this is necessary. Another possibility of avoiding the inexpedient narrow-band restriction consists in the simultaneous application of different chamber lengths according to the [US] German Patent Document 196 12 572.

Another group of sound attenuators or absorbers for low frequencies comprises resonant cavities, i.e. both acoustic waveguides according to Okamoto, Y.; Boden, H.; Abom, M.: "Active noise control in ducts via side-branch resonators" in: Journ. of the Acoust. Soc. of America 96 (1994), No. 9, pp. 1533 - 1538, and equally Helmholtz resonators according to [the German Patent] DE 4226885 or the US Patent No. 5233137, which are connected to a sound-transmitting duct or space via an

opening and which have properties suitable for variation by [means of] electro-acoustical or active components, respectively. These systems share the joint approach that at least one microphone is present in the duct or space. The sound pressure signal so detected is initially filtered, amplified and subjected to further analysis steps and then serves as control variable for at least one loudspeaker in the waveguide or cavity. As a result, the loudspeaker emits a signal[,] which, again upon modification by the resonator, is superimposed with opposite phase onto the sound at the site of the microphone in the duct or cavity, so effecting attenuation of the sound. With these actively influenced resonators, it is possible, on the one hand, to generate and hence also attenuate high sound pressures at low frequencies [whilst] while, on the other hand, at least the loudspeaker is protected from potential, e.g. thermal, loads in the duct. The disadvantages of these methods include the fixed dimensioning of the resonators independently of possible variations of the sound spectrum in the duct, which is initially taken as a basis, and the lack of protection of the microphone.

According to [the German Patent] DE 4027511, a passive sub-system is used instead of the resonant cavities so far mentioned, which consists preferably of passive absorber layers and protecting cover layers. In this case, too, the function of the electro-acoustical components mounted on the rear side relates to the modification of the passive absorber, aiming at the generation of a theoretically optimum acoustic impedance on the front side of the absorber, which impedance promise the highest propagation attenuation possible in the connected sound-transmitting duct. This method requires that a signal-shaping circuit proposed in [the German Patent] DE 4027511

firstly compensates the intrinsic characteristics of all the electro-acoustic components (microphone, loudspeaker, box, etc.) and secondly imprints on the system the desired terminating impedance. The characteristics of the components have been thoroughly studied and described. In accordance with the results the conversion of this method into practice inevitably requires the implementation of complex transmission functions of the signal-shaping circuit, which cannot be realised in practical application except in approximation.

Reactive sound absorbers are operative without any additional passive layers or resonance systems [in correspondence with the document] according to WO 97/43754, wherein the membrane of a loudspeaker is a direct component of the wall in a sound-transmitting duct and wherein the membrane vibrations controlled or amplified [by means of] with a feed-back circuit take a direct influence on the sound field in the duct. The adaptation to a sound spectrum to be attenuated, which is also necessary in this case[, too], is based on the dimensioning of the resonance system consisting of the membrane mass and the pneumatic cushion in the form of the rear volume, which exists there-behind.

SUMMARY OF THE INVENTION

It is an object of the present invention to improve the efficiency of sound attenuation in ducts or the like and to reduce the manufacturing costs of the inventive device.

This problem [is] has been solved by the device [according to Claim 1. Expedient improvements of the invention are characterised in the dependent Claims] of the present invention in which the longitudinal resonances of said hollow chamber are

tunable to a sound spectrum to be attenuated, by detecting the membrane vibrations by a microphone located directly in front of the membrane of at least one loudspeaker on the second end surface of said hollow chamber, and by inverting the microphone signal by an amplifier and by feedback of the inverted microphone signal to said loudspeaker in an amplified form in dependence on a signal from a sensor, which is characteristic of the sound in the duct.

[3. Description]

[The starting point of the inventive controlled waveguide according to Fig. 1 consists in an elongate hollow chamber (1) presenting distinct longitudinal resonances, which is acoustically connected via an opening (2) on the first end surface (3) to a sound-transmitting duct (4) or space. The length L of the hollow chamber (1) is dependent on the sound spectrum occurring in the duct, wherein the frequencies with the greatest sound amplitude vary within a defined range, e. g. as a consequence of a varying gas temperature in the duct (4), as a function of the operation. In this case the length L corresponds to roughly one quarter of the wavelength of the upper limit frequency of this range. The membrane (8) of at least one loudspeaker (9) is provided on the second end surface (6) of the hollow chamber (1), in front of another cavity (7), with the cavity (7) as air cushion and the membrane (8) as planar mass forming a resonance system. A microphone (10) is positioned directly in front of the membrane for detecting the membrane vibrations. The microphone signal is applied on the input of an inverting amplifier (11) with an adjustable gain, which produces an output signal, which serves to control the

loudspeaker (9). As a function of the level of amplification the membrane vibrations hence the acoustically effective length of the hollow chamber (1) undergo a variation, with the acoustic length being definitely (roughly four times) greater than the actual length L. The acoustically effective prolongation of the hollow chamber (1), which is achieved on account of the increased amplification, means a shift of its first longitudinal resonance towards lower frequencies, expediently up to the lower limit of the frequency range of the sound spectrum occurring in the duct (4). The setting of the gain is based on the control signal of at least one additional sensor (12) which supplies a parameter to the amplifier (11), that is characteristic of the frequencies having the highest sound amplitude in the duct.

Temperature sensors in the duct (4), rotational speed detectors on ventilators, generators or motors or engines, as well as elements measuring the gas flow of burners and exhaust systems may be enumerated as examples of a sensor (12). The sensor (12) is expediently operative without particular protective measures such as those required, for instance, in microphones in an exhaust system. An exemplary and particularly simple configuration of the sensor (12) is a temperature-dependent resistor which detects the temperature in the duct (4) and constitutes, at the same time, an element of the feedback branch of an inverting amplifier (11) known per se and hence controls the overall gain achieved by this amplifier. Further expedient embodiments include the application of voltage- and current-controlled amplifiers (11) [and] which broaden the range of conceivable sensors (12) available for selection.

A sound-transmitting cover (5) consisting of perforated sheet,

non-woven material, sheet material or the like is provided in front of or behind the opening (2) leading to the duct (4) for protection from a possible soiling of the hollow chamber (1) and from entering hot exhaust gas from the duct (4). As a function of structural conditions in the environment of the duct (4), the hollow chamber (1) may present a straight or curved shape, project obliquely or orthogonally from the duct, or conform against the duct (4) in the longitudinal direction. In this case, a thermal insulating layer (13) is disposed between the hollow chamber (1) and the duct (4), as may be seen in Fig. 2. Whenever the hollow chamber (1) must be expected to be heated the cooling elements (14) illustrated in Fig. 2 as part of the wall of the hollow chamber improve the dissipation of heat in the same manner as a forced cooling means (15) of the kind of a thermal exchanger or with so-called Peltier elements in the hollow chamber. A transverse subdivision (16) of the hollow chamber (1) into several tubes of different lengths as well as an absorbing inner wall cladding (17) constitute expedient embodiments of the inventive controlled waveguide (Fig. 3) so as to achieve a broader-band attenuation.

Fig. 4 illustrates an exemplary embodiment of the inventive controlled waveguide. The attenuation levels achieved in combination with a conventional passive attenuator (18) on the opposite duct wall, which are indicated in Fig. 5, represent the two boundary cases in the frequency range as a function of the set gain (11). The contrastive indication of the attenuation measured at 20 °C and 150 °C in the duct, which is presented in Fig. 6, emphasizes the low influence of temperature on the attenuation of the inventive controlled waveguide according to Fig. 4.]

[4. Advantages over Prior Art]

The advantages of the present invention over existing sound absorber[s, which are entailed by the inventive controlled waveguide, relate to] includes the following features:

- In distinction from known acoustic waveguides, the [inventive] controlled waveguide of the present invention achieves a high sound attenuation at low frequencies at a reduced structural volume (with the length of the hollow chambers reduced by up to roughly four times).

- The frequency range with a high sound absorption of the inventive controlled waveguide is extended to roughly [2] two octaves due to the adaptivity to variable acoustic spectrums.

- The [inventive] controlled waveguide of the present invention is characterized by a simple structure and particularly by a low-price analog amplification and control without expensive electronic filters or digital signal analysis,

- Furthermore, all the electro-acoustic components in the hollow chamber of the [inventive] controlled waveguide of the present invention are protected from influences produced by flow, dust and aggressive media in the duct over rather long periods.

- This protection is also extended to high temperature, e.g. in exhaust gas systems, because the inventive controlled waveguide offers various possibilities of an

efficient thermal decoupling from the duct.

[5.] Brief Description of the Drawings

Other objects, advantages and novel features of the present invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings.

Fig. 1[:] [structure] is a schematic view of the [inventive] controlled waveguide in accordance with the present invention;

Fig. 2[:] [expedient embodiments] is a schematic view of an embodiment of the [inventive] controlled waveguide with a thermal insulating layer [(13)] between the hollow chamber [(1)] and the duct [(4)], with cooling elements [(14)] as part of the wall of the hollow chamber, with a forced cooling [means (15) in the manner of a] thermal exchanger, as well as with an absorbing inner wall cladding [(17)];

Fig. 3[:] [expedient embodiments] is a schematic view of another embodiment of the [inventive] controlled waveguide of the present invention with a subdivision of the hollow chamber [(1)] into several tubes [(16)] of different lengths;

Fig. 4[:] [exemplary] is a schematic view of still another embodiment of the [inventive] controlled waveguide with a conventional passive attenuator [(18)] on the opposite duct

wall (with dimensions indicated in mm);

Fig. 5[:] is a graph of insertion attenuation measured on the [exemplary] controlled waveguide according to Fig. 4, with and without amplification;

Fig. 6[:] is a graph of insertion attenuation measured on the [exemplary] controlled waveguide according to Fig. 4, with amplification at an air temperature of 20 °C and 150 °C in the duct [(4)];

Fig. 7[: exemplary] is a schematic view of a controlled waveguide with a hollow chamber [(1)] projecting obliquely from the duct [(4)];

Fig. 8[: exemplary] is a schematic view of a controlled waveguide with a hollow chamber [(1)] conforming to a bent duct [(4)];

Fig. 9[: exemplary] is a schematic view of a controlled waveguide with an aerodynamically expedient [design] configuration and positioning in the manner of a central slide inside a large duct [(4)]; and.

Fig. 10 is a schematic view of yet another embodiment of a controlled waveguide

DETAILED DESCRIPTION OF THE DRAWINGS

The starting point of the controlled waveguide according to Fig. 1 consists in an elongate hollow chamber (1) presenting

distinct longitudinal resonances. The chamber (1) is acoustically connected via an opening (2) on the first end surface (3) to a sound-transmitting duct (4) or space. The length L of the hollow chamber (1) is dependent on the sound spectrum occurring in the duct (4), wherein the frequencies with the greatest sound amplitude vary within a defined range, e. g. as a consequence of a varying gas temperature in the duct (4), as a function of the operation. In this case the length L corresponds to roughly one quarter of the wavelength of the upper limit frequency of this range.

The membrane (8) of at least one loudspeaker (9) is provided on the second end surface (6) of the hollow chamber (1), in front of another cavity (7), with the cavity (7) acting as air cushion and the membrane (8) as planar mass forming a resonance system. A microphone (10) is positioned directly in front of the membrane for detecting the membrane vibrations. The microphone signal is applied on the input of an inverting amplifier (11) with an adjustable gain, which produces an output signal, which serves to control the loudspeaker (9).

As a function of the level of amplification the membrane vibrations hence the acoustically effective length of the hollow chamber (1) undergo a variation, with the acoustic length being definitely (roughly four times) greater than the actual length L. The acoustically effective prolongation of the hollow chamber (1), which is achieved on account of the increased amplification, means a shift of its first longitudinal resonance towards lower frequencies, expediently up to the lower limit of the frequency range of the sound spectrum occurring in the duct (4). The setting of the gain is based on the control signal of at least one additional sensor

(12) which supplies a parameter to the amplifier (11) that is characteristic of the frequencies having the highest sound amplitude in the duct.

Temperature sensors in the duct (4), rotational speed detectors on ventilators, generators or motors or engines, as well as elements measuring the gas flow of burners and exhaust systems may be enumerated as examples of a sensor (12). The sensor (12) is expediently operative without particular protective measures such as those required, for instance, in microphones in an exhaust system. An exemplary and particularly simple configuration of the sensor (12) is a temperature-dependent resistor which detects the temperature in the duct (4) and constitutes, at the same time, an element of the feedback branch of an inverting amplifier (11) known per se and hence controls the overall gain achieved by this amplifier. Further expedient embodiments include the application of voltage- and current-controlled amplifiers (11) [and] which broaden the range of contemplated sensors (12) available for selection.

A sound-transmitting cover (5) consisting of perforated sheet, non-woven material, sheet material or the like is provided in front of or behind the opening (2) leading to the duct (4) for protection from a possible soiling of the hollow chamber (1) and from entering hot exhaust gas from the duct (4). As a function of structural conditions in the environment of the duct (4), the hollow chamber (1) may be configured in a straight or curved shape, project obliquely or orthogonally from the duct, or conform against the duct (4) in the longitudinal direction. In this case, a thermal insulating layer (13) is disposed between the hollow chamber (1) and the duct (4), as may be seen in Fig. 2. Whenever the hollow chamber

(1) must be expected to be heated, the cooling elements (11) illustrated in Fig. 2 as part of the wall of the hollow chamber improve the dissipation of heat in the same manner as a forced cooling [means (15)] of the kind of a thermal exchanger (15) or with so-called Peltier elements in the hollow chamber. A transverse subdivision (16) of the hollow chamber (1) into several tubes of different lengths as well as an absorbing inner wall cladding (17) constitute another advantageous embodiment of the inventive controlled waveguide (Fig. 3) so as to achieve a broader-band attenuation.

Fig. 4 illustrates an embodiment of the inventive controlled waveguide in which the attenuation levels achieved in combination with a conventional passive attenuator (18) on the opposite duct wall, which are indicated in Fig. 5, represent the two boundary cases in the frequency range as a function of the set gain (11). The contrastive indication of the attenuation measured at 20 °C and 150 °C in the duct, which is presented in Fig. 6, emphasizes the low influence of temperature on the attenuation of the inventive controlled waveguide according to Fig. 4.

Figs. 7 through 10 show further embodiments of the controlled waveguide of the present invention. Similar reference numerals have been used to designate parts having functions similar to the described in conjunction with the embodiments of Figs. 1 through 4

The foregoing disclosure has been set forth merely to illustrate the invention and is not intended to be limiting. Since modifications of the disclosed embodiments incorporating the spirit and substance of the invention may occur to persons skilled in the art, the invention should be construed to

include everything within the scope of the appended claims and equivalents thereof.

[6. Literature

[1] [German Patent DE 19612572, Cleanable sound absorber for low frequencies]

[2] [Lamancusa, J.S.: "An actively tuned passive muffler system for engine silencing". Proceedings Noise-Con 87, 1987, pp. 313 - 318]

[3] [US Patent 3913702, Cellular sound absorptive structure]

[4] [Okamoto, Y.; Boden, H.; Abom, M.: Active noise control in ducts via side-branch resonators; in: Journ. of the Acoust. Soc. of America 96 (1994), No. 9, pp. 1533 - 1538]

[5] [German Patent DE 4226885, Sound absorption method for motor vehicles]

(6) [US Patent 5233137, Protective ANC loudspeaker membrane]

[7] [German Patent DE 4027511, Hybrid sound attenuator]

[8] [Lippold, R., Lenk, A.: "Sound attenuation in ducts presenting actively generated wall admittances", in: Acustica 81 (1995), No. 4, pp. 356 - 363]

[9] [WO 97/43754, Reactive sound absorber]

Patent Claims

1. Controlled acoustic waveguide of the type of an elongate hollow chamber (1), which is connected to a sound-transmifting duct (4) via an opening (2) on its first end surface (3), **characterised** in that the longitudinal resonances of said hollow chamber (1) are tunable to a sound spectrum to be attenuated, by detecting the membrane vibrations by means of a microphone (10) located directly in front of the membrane (8) of at least one loudspeaker (9) on the second end surface (6) of said hollow chamber (1), and by inverting the microphone signal by means of an amplifier (11) and by feedback of the inverted microphone signal to said loudspeaker (9) in an amplified form in dependence on a signal from a sensor (12), which is characteristic of the sound in said duct (4).

2. Controlled waveguide according to Claim 1, **characterised** in that said opening (23) is provided with a sound-transmifting protective cover (5) made of a perforated sheet, a non-woven material or sheet materials.

3. Controlled waveguide according to Claims 1 and 2, **characterised** in that said hollow chamber (1) projects orthogonally or obliquely from said duct (4) or conforms to the straight or bent wall of the duct.

4. Controlled waveguide according to the Claims 1 to 3, **characterised** in that a thermal insulating layer (13)

is provided between the duct wall and the wall of said hollow chamber when said hollow chamber (1) conforms to the wall of said duct (4).

5. Controlled waveguide according to the Claims 1 to 4, **characterised** in that the wall of said hollow chamber (1) are provided with cooling elements (11) either over part of their surface or their entire surface.

6. Controlled waveguide according to the Claims 1 to 5, **characterised** in that a forced cooling (15) means of the type of a thermal exchanger or Peltier elements is provided in said hollow chamber (1).

7. Controlled waveguide according to the Claims 1 to 6, **characterised** in that said hollow chamber (1) is subdivided into tubes of different lengths by means of a transverse partitioning.

8. Controlled waveguide according to the Claims 1 to 7, **characterised** in that the walls of said hollow chamber (1) are provided with a sound absorptive cladding (17) either over parts of their surface or their entire surface.

9. Controlled waveguide according to the Claims 1 to 7, **characterised** in that temperature sensors, rotational speed sensors as well as measuring elements for the gas flow of burners and exhaust gas systems are employed as sensor (12) for the sound spectrum occurring in said duct (4).

10. Controlled waveguide according to the Claims 1 to 9, **characterised** in that several controlled waveguides are used on several side walls of ducts (4) having a rectangular cross-section.

11. Controlled waveguide according to the Claims 1 to 9, **characterised** in that a c circular hollow chamber (1) is used which extends along the periphery about a cylindrical duct (4).

12. Controlled waveguide according to the Claims 1, 2 and 6 to 9, **characterised** in that the controlled waveguide presents an aerodynamically expedient design and is positioned in the manner of a central slide inside a large rectangular or cylindrical duct (4).

13. Controlled waveguide according to the Claims 1 and 3 to 9, **characterised** in that an acoustically effective membrane or plate instead of said sound-transmitting opening (2) constitutes the communication with said duct (4).

Abstract of the disclosure

The present invention relates to a controlled acoustic waveguide of the type of an elongate hollow chamber (1) which communicates with a sound-transmitting duct (4) via an opening (2) in its first end surface (3), wherein the longitudinal resonances of the hollow chamber (1) may be tuned to a sound spectrum to be attenuated, by detecting the membrane vibrations by means of a microphone (10) located directly in front of the membrane (8) of at least one loudspeaker (9) on the second end surface (6) of said hollow chamber (1), and by inverting the microphone signal by means of an amplifier (11) and by feedback of the inverted microphone signal to said loudspeaker (9) in an amplified form in dependence on a signal from a sensor (12), which is characteristic of the sound in said duct (4).

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Controlled Acoustic Waveguide for Sound Absorption

Description

1. Subject matter of the invention

The present invention relates to a controlled acoustic waveguide for sound absorption in the manner of an elongate hollow chamber, which communicates with a sound-transmitting duct via an opening on its first end surface and wherein the longitudinal resonances may be tuned to a sound spectrum to be attenuated, by detecting the membrane vibrations by means of a microphone located directly in front of the membrane of at least one loudspeaker on the second end surface of the hollow chamber, and by inverting the microphone signal by means of an amplifier and by feedback of the inverted microphone signal to the loudspeaker in an amplified form in dependence on a signal from a sensor, which is characteristic of the sound in the duct.

2. Prior Art

Sound absorbers are known for attenuating low-frequency noise in ducts, wherein the longitudinal resonances of elongate hollow chambers, so-called acoustic waveguides, are utilised, e.g. in accordance with the German Patent DE 19612572 or Lamancusa, J.S.: "An actively tuned passive muffler system for engine silencing". Proceedings Noise-Con 87, 1987, pp. 313 - 318. These waveguides are coupled to the sound-transmitting duct via an opening in the end surface thereof and either project orthogonally from the duct or conform thereto while extending in parallel therewith. For the first longitudinal resonance in particular, at which the length of the chamber corresponds to one quarter of the wavelength of the first resonance frequency, high attenuation levels are achieved over a narrow band. This limitation of the frequency range is, however, problematic when either a wide-band absorption is required or when the noise spectrum changes which was taken as a basis when the waveguide was dimensioned. The necessary adaptation of the chamber length is implemented, at least in stages, according to Lamancusa, by the provision of very long chambers with compartments from the very beginning, which may

provision of very long chambers with compartments from the very beginning, which may be opened or closed whenever this is necessary. Another possibility of avoiding the inexpedient narrow-band restriction consists in the simultaneous application of different chamber lengths according to the DE [US Patent] 196 12 572.

Another group of sound attenuators or absorbers for low frequencies comprises resonant cavities, i.e. both acoustic waveguides according to Okamoto, Y.; Boden, H.; Abom, M.: "Active noise control in ducts via side-branch resonators" in: Journ. of the Acoust. Soc. of America 96 (1994), No. 9, pp. 1533 - 1538, and equally Helmholtz resonators according to the German Patent DE 4226885 or the US Patent 5233137, which are connected to a sound-transmitting duct or space via an opening and which have properties suitable for variation by means of electro-acoustical or active components, respectively. These systems share the joint approach that at least one microphone is present in the duct or space. The sound pressure signal so detected is initially filtered, amplified and subjected to further analysis steps and then serves as control variable for at least one loudspeaker in the waveguide or cavity. As a result, the loudspeaker emits a signal, which, again upon modification by the resonator, is superimposed with opposite phase onto the sound at the site of the microphone in the duct or cavity, so effecting attenuation of the sound. With these actively influenced resonators it is possible, on the one hand, to generate and hence also attenuate high sound pressures at low frequencies whilst, on the other hand, at least the loudspeaker is protected from potential, e.g. thermal, loads in the duct. The disadvantages of these methods include the fixed dimensioning of the resonators independently of possible variations of the sound spectrum in the duct, which is initially taken as a basis, and the lack of protection of the microphone.

According to the German Patent DE 4027511 a passive sub-system is used instead of the resonant cavities so far mentioned, which consists preferably of passive absorber layers and protecting cover layers. In this case, too, the function of the electro-acoustical components mounted on the rear side relates to the modification of the passive absorber, aiming at the generation of a theoretically optimum acoustic impedance on the front side of the absorber, which impedance promise the highest propagation attenuation possible in the connected sound-transmitting duct. This method requires that a signal-shaping circuit proposed in the German Patent DE 4027511 firstly compensates the intrinsic characteristics of all the electro-acoustic components (microphone, loudspeaker, box,

etc.) and secondly imprints on the system the desired terminating impedance. The characteristics of the components have been thoroughly studied and described. In accordance with the results the conversion of this method into practice inevitably requires the implementation of complex transmission functions of the signal-shaping circuit, which cannot be realised in practical application except in approximation.

Reactive sound absorbers are operative without any additional passive layers or resonance systems in correspondence with the document WO 97/43754, wherein the membrane of a loudspeaker is a direct component of the wall in a sound-transmitting duct and wherein the membrane vibrations controlled or amplified by means of a feed-back circuit take a direct influence on the sound field in the duct. The adaptation to a sound spectrum to be attenuated, which is necessary in this case, too, is based on the dimensioning of the resonance system consisting of the membrane mass and the pneumatic cushion in the form of the rear volume, which exists there-behind.

It is an object of the present invention to improve the efficiency of sound attenuation in ducts or the like and to reduce the manufacturing costs of the inventive device.

This problem is solved by the device according to Claim 1. Expedient improvements of the invention are characterised in the dependent Claims.

3. Description

The starting point of the inventive controlled waveguide according to Fig. 1 consists in an elongate hollow chamber (1) presenting distinct longitudinal resonances, which is acoustically connected via an opening (2) on the first end surface (3) to a sound-transmitting duct (4) or space. The length L of the hollow chamber (1) is dependent on the sound spectrum occurring in the duct, wherein the frequencies with the greatest sound amplitude vary within a defined range, e. g. as a consequence of a varying gas temperature in the duct (4), as a function of the operation. In this case the length L corresponds to roughly one quarter of the wavelength of the upper limit frequency of this range. The membrane (8) of at least one loudspeaker (9) is provided on the second end surface (6) of the hollow chamber (1), in front of another cavity (7), with the cavity (7) as air cushion and the membrane (8) as planar mass forming a resonance system. A microphone (10) is positioned directly in front of the membrane for detecting the

membrane vibrations. The microphone signal is applied on the input of an inverting amplifier (11) with an adjustable gain, which produces an output signal, which serves to control the loudspeaker (9). As a function of the level of amplification the membrane vibrations hence the acoustically effective length of the hollow chamber (1) undergo a variation, with the acoustic length being definitely (roughly four times) greater than the actual length L. The acoustically effective prolongation of the hollow chamber (1), which is achieved on account of the increased amplification, means a shift of its first longitudinal resonance towards lower frequencies, expediently up to the lower limit of the frequency range of the sound spectrum occurring in the duct (4). The setting of the gain is based on the control signal of at least one additional sensor (12) which supplies a parameter to the amplifier (11), that is characteristic of the frequencies having the highest sound amplitude in the duct.

Temperature sensors in the duct (4), rotational speed detectors on ventilators, generators or motors or engines, as well as elements measuring the gas flow of burners and exhaust systems may be enumerated as examples of a sensor (12). The sensor (12) is expediently operative without particular protective measures such as those required, for instance, in microphones in an exhaust system. An exemplary and particularly simple configuration of the sensor (12) is a temperature-dependent resistor which detects the temperature in the duct (4) and constitutes, at the same time, an element of the feedback branch of an inverting amplifier (11) known per se and hence controls the overall gain achieved by this amplifier. Further expedient embodiments include the application of voltage- and current-controlled amplifiers (11) and broaden the range of conceivable sensors (12) available for selection.

A sound-transmitting cover (5) consisting of perforated sheet, non-woven material, sheet material or the like is provided in front of or behind the opening (2) leading to the duct (4) for protection from a possible soiling of the hollow chamber (1) and from entering hot exhaust gas from the duct (4). As a function of structural conditions in the environment of the duct (4), the hollow chamber (1) may present a straight or curved shape, project obliquely or orthogonally from the duct, or conform against the duct (4) in the longitudinal direction. In this case, a thermal insulating layer (13) is disposed between the hollow chamber (1) and the duct (4), as may be seen in Fig. 2. Whenever the hollow chamber (1) must be expected to be heated the cooling elements (14) illustrated in Fig. 2 as part of the

wall of the hollow chamber improve the dissipation of heat in the same manner as a forced cooling means (15) of the kind of a thermal exchanger or with so-called Peltier elements in the hollow chamber. A transverse subdivision (16) of the hollow chamber (1) into several tubes of different lengths as well as an absorbing inner wall cladding (17) constitute expedient embodiments of the inventive controlled waveguide (Fig. 3) so as to achieve a broader-band attenuation.

Fig. 4 illustrates an exemplary embodiment of the inventive controlled waveguide. The attenuation levels achieved in combination with a conventional passive attenuator (18) on the opposite duct wall, which are indicated in Fig. 5, represent the two boundary cases in the frequency range as a function of the set gain (11). The contrastive indication of the attenuation measured at 20 °C and 150 °C in the duct, which is presented in Fig. 6, emphasizes the low influence of temperature on the attenuation of the inventive controlled waveguide according to Fig. 4.

4. Advantages over Prior Art

The advantages over existing sound absorbers, which are entailed by the inventive controlled waveguide, relate to the following features:

- In distinction from known acoustic waveguides, the inventive controlled waveguide achieves a high sound attenuation at low frequencies at a reduced structural volume (length of the hollow chambers reduced by up to roughly four times).

- The frequency range with a high sound absorption of the inventive controlled waveguide is extended to roughly 2 octaves due to the adaptivity to variable acoustic spectrums.

- The inventive controlled waveguide is characterized by a simple structure and particularly by a low-price analog amplification and control without expensive electronic filters or digital signal analysis.

- Furthermore, all the electro-acoustic components in the hollow chamber of the inventive controlled waveguide are protected from influences produced by flow, dust and aggressive media in the duct over rather long periods.

- This protection is also extended to high temperature, e.g. in exhaust gas systems, because the inventive controlled waveguide offers various possibilities of an efficient thermal decoupling from the duct.

5. Description of the Drawings

Fig. 1: structure of the inventive controlled waveguide;

Fig. 2: expedient embodiments of the inventive controlled waveguide with a thermal insulating layer (13) between the hollow chamber (1) and the duct (4), with cooling elements (14) as part of the wall of the hollow chamber, with a forced cooling means (15) in the manner of a thermal exchanger, as well as with an absorbing inner wall cladding (17);

Fig. 3: expedient embodiments of the inventive controlled waveguide with a subdivision of the hollow chamber (1) into several tubes (16) of different lengths;

Fig. 4: exemplary embodiment of the inventive controlled waveguide with a conventional passive attenuator (18) on the opposite duct wall (dimensions in mm);

Fig. 5: insertion attenuation measured on the exemplary controlled waveguide according to Fig. 4, with and without amplification;

Fig. 6: insertion attenuation measured on the exemplary controlled waveguide according to Fig. 4, with amplification at an air temperature of 20 °C and 150 °C in the duct (4);

Fig. 7: exemplary controlled waveguide with a hollow chamber (1) projecting obliquely from the duct (4);

Fig. 8: exemplary controlled waveguide with a hollow chamber (1) conforming to a bent duct (4);

Fig. 9: exemplary controlled waveguide with an aerodynamically expedient design and positioning in the manner of a central slide inside a large duct (4).

6. Literature

[1] German Patent DE 19612572, Cleanable sound absorber for low frequencies

[2] Lamancusa, J.S.: "An actively tuned passive muffler system for engine silencing". Proceedings Noise-Con 87, 1987, pp. 313 – 318

[3] US Patent 3913702, Cellular sound absorptive structure

[4] Okamoto, Y.; Boden, H.; Abom, M.: Active noise control in ducts via side-branch resonators; in: Journ. of the Acoust. Soc. of America 96 (1994), No. 9, pp. 1533 – 1538

[5] German Patent DE 4226885, Sound absorption method for motor vehicles

[6] US Patent 5233137, Protective ANC loudspeaker membrane

[7] German Patent DE 4027511, Hybrid sound attenuator

[8] Lippold, R., Lenk, A.: "Sound attenuation in ducts presenting actively generated wall admittances", in: Acustica 81 (1995), No. 4, pp. 356 – 363

[9] WO 97/43754, Reactive sound absorber

Patent Claims

1. Controlled acoustic waveguide of the type of an elongate hollow chamber (1), which is connected to a sound-transmitting duct (4) via an opening (2) on its first end surface (3), **characterised** in that the longitudinal resonances of said hollow chamber (1) are tunable to a sound spectrum to be attenuated, by detecting the membrane vibrations by means of a microphone (10) located directly in front of the membrane (8) of at least one loudspeaker (9) on the second end surface (6) of said hollow chamber (1), and by inverting the microphone signal by means of an amplifier (11) and by feedback of the inverted microphone signal to said loudspeaker (9) in an amplified form in dependence on a signal from a sensor (12), which is characteristic of the sound in said duct (4).

2. Controlled waveguide according to Claim 1, **characterised** in that said opening (23) is provided with a sound-transmitting protective cover (5) made of a perforated sheet, a non-woven material or sheet materials.

3. Controlled waveguide according to Claims 1 and 2, **characterised** in that said hollow chamber (1) projects orthogonally or obliquely from said duct (4) or conforms to the straight or bent wall of the duct.

4. Controlled waveguide according to the Claims 1 to 3, **characterised** in that a thermal insulating layer (13) is provided between the duct wall and the wall of said hollow chamber when said hollow chamber (1) conforms to the wall of said duct (4).

5. Controlled waveguide according to the Claims 1 to 4, **characterised** in that the wall of said hollow chamber (1) are provided with cooling elements (11) either over part of their surface or their entire surface.

6. Controlled waveguide according to the Claims 1 to 5, **characterised** in that a forced cooling (15) means of the type of a thermal exchanger or Peltier elements is provided in said hollow chamber (1).

7. Controlled waveguide according to the Claims 1 to 6, **characterised** in that said hollow chamber (1) is subdivided into tubes of different lengths by means of a transverse partitioning.

8. Controlled waveguide according to the Claims 1 to 7, **characterised** in that the walls of said hollow chamber (1) are provided with a sound absorptive cladding (17) either over parts of their surface or their entire surface.

9. Controlled waveguide according to the Claims 1 to 7, **characterised** in that temperature sensors, rotational speed sensors as well as measuring elements for the gas flow of burners and exhaust gas systems are employed as sensor (12) for the sound spectrum occurring in said duct (4).

10. Controlled waveguide according to the Claims 1 to 9, **characterised** in that several controlled waveguides are used on several side walls of ducts (4) having a rectangular cross-section.

11. Controlled waveguide according to the Claims 1 to 9, **characterised** in that a c circular hollow chamber (1) is used which extends along the periphery about a cylindrical duct (4).

12. Controlled waveguide according to the Claims 1, 2 and 6 to 9, **characterised** in that the controlled waveguide presents an aerodynamically expedient design and is positioned in the manner of a central slide inside a large rectangular or cylindrical duct (4).

13. Controlled waveguide according to the Claims 1 and 3 to 9, **characterised** in that an acoustically effective membrane or plate instead of said sound-transmitting opening (2) constitutes the communication with said duct (4).

Abstract of the disclosure

The present invention relates to a controlled acoustic waveguide of the type of an elongate hollow chamber (1) which communicates with a sound-transmitting duct (4) via an opening (2) in its first end surface (3), wherein the longitudinal resonances of the hollow chamber (1) may be tuned to a sound spectrum to be attenuated, by detecting the membrane vibrations by means of a microphone (10) located directly in front of the membrane (8) of at least one loudspeaker (9) on the second end surface (6) of said hollow chamber (1), and by inverting the microphone signal by means of an amplifier (11) and by feedback of the inverted microphone signal to said loudspeaker (9) in an amplified form in dependence on a signal from a sensor (12), which is characteristic of the sound in said duct (4).

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Attorney Docket No. 127FR/49857
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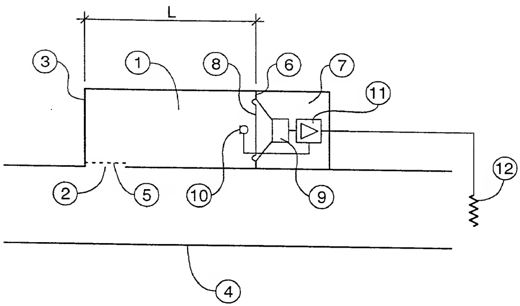

Fig. 1

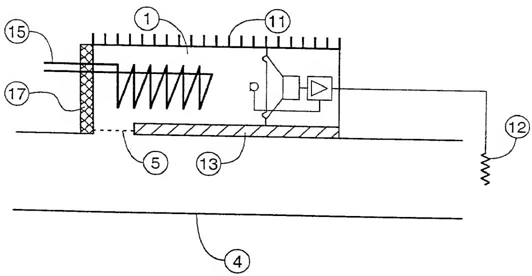

Fig. 2

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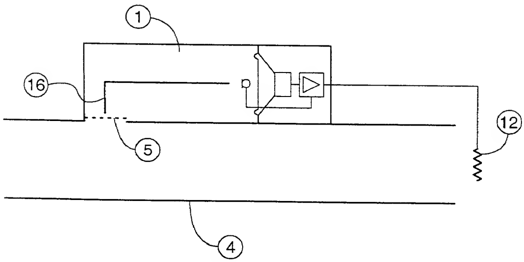

Fig. 3

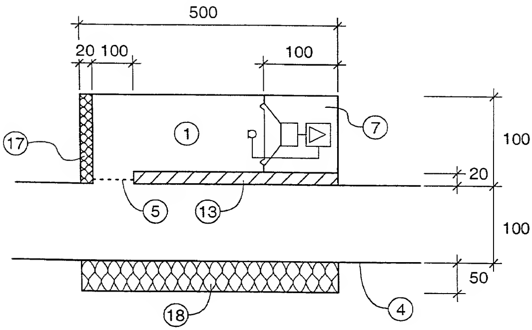

Fig. 4

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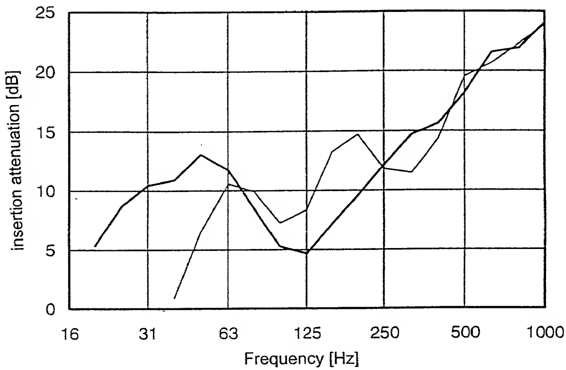

controlled waveguide according to Fig. 4 with amplifier (11) turned on at 20 °C in the duct (4)

controlled waveguide according to Fig. 4 with amplifier (11) turned on at 150 °C in the duct (4)

Fig. 5

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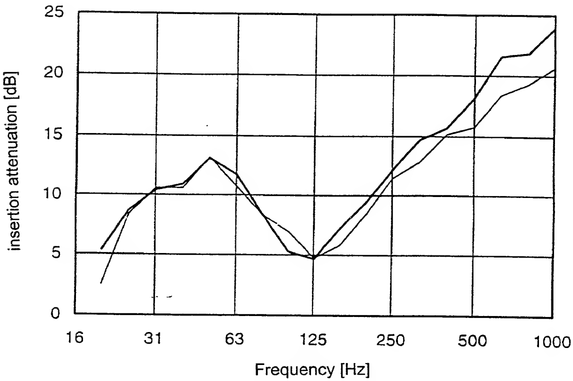

controlled waveguide according to Fig. 4 with amplifier (11) turned on

controlled waveguide according to Fig. 4 with amplifier (11) turned off

Fig. 6

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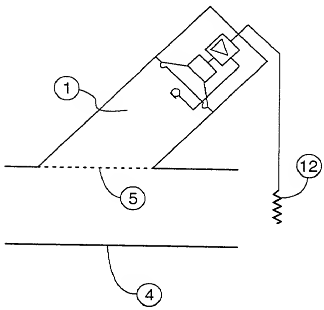

Fig. 7

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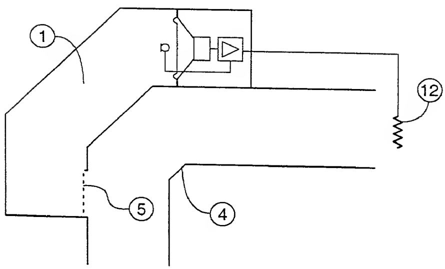

Fig. 8

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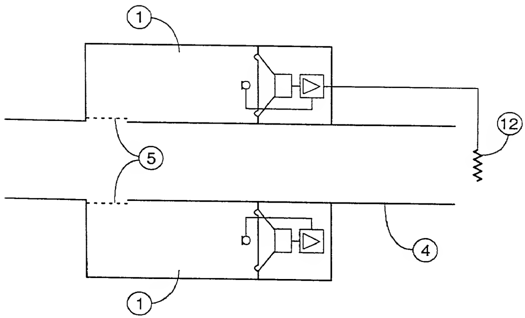

Fig. 9

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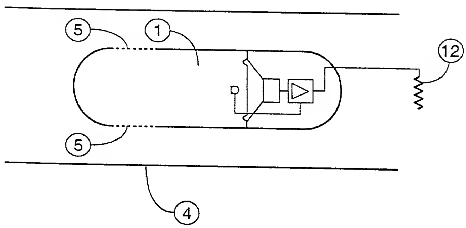

Fig. 10

COMBINED DECLARATION FOR PATENT APPLICATION AND POWER OF ATTORNEY (includes Reference to PCT International Applications)	ATTORNEY'S DOCKET NUMBER 127FR/49857

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

Controlled Acoustic Waveguide for Sound Absorption

the specification of which (check only one item below):

[ ] is attached hereto.

[ ] was filed as United States application
Serial No. ______
on ______
and was amended
on ______ (if applicable).

[X] was filed as PCT international application
Number PCT/EP99/09966
on December 15, 1999
and was amended under PCT Article 19
on ______ (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations. §1.56(a).

I hereby claim foreign priority benefits under Title 35, United State Code, §119 of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed:

PRIOR FOREIGN/PCT APPLICATION(S) AND ANY PRIORITY CLAIMS UNDER 35 U.S.C. 119:

COUNTRY (if PCT indicate PCT)	APPLICATION NUMBER	DATE OF FILING (day, month, year)	PRIORITY CLAIMED UNDER 35 USC 119
Germany	198 61 018.1	15 December 1998	[X] Yes [ ] No
			[ ] Yes [ ] No
			[ ] Yes [ ] No
			[ ] Yes [ ] No
			[ ] Yes [ ] No

Combined Declaration For Patent Application and Power of Attorney (Continued) (includes Reference to PCT international Applications	ATTORNEY'S DOCKET NUMBER 127FR/49857

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) or PCT international application(s) designating the United States of America that is/are listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in that/those prior application(s) in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occurred between the filing date of the prior application(s) and the national of PCT international filing date of this application:

PRIOR U.S. APPLICATIONS OR PCT INTERNATIONAL APPLICATIONS DESIGNATING THE U.S. FOR BENEFIT UNDER 35 U.S.C. 120

U.S. APPLICATIONS		STATUS (*Check one*)		
U.S. APPLICATION NUMBER	U.S. FILING DATE	PATENTED	PENDING	ABANDONED

PCT APPLICATIONS DESIGNATING THE U.S.					
PCT APPLICATION NO	PCT FILING DATE	U.S. SERIAL NUMBERS ASSIGNED (IF ANY)			

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. (List name and registration number)

8

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	POST OFFICE ADDRESS	POST OFFICE ADDRESS	CITY	STATE & ZIP CODE/COUNTRY

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true: and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

SIGNATURE OF INVENTOR 201	SIGNATURE OF INVENTOR 202	SIGNATURE OF INVENTOR 203
J. Krüger	[signature]	
DATE 14.7.2001	Date 12.7.2001	DATE